RETROFIT OF BLAST CHAMBERS FOR EXPLOSIVES CAUSING CHEMICAL OR BIOLOGICAL HAZARDS

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Abstract

Recent national and international terrorist events have created a need for disposing of munitions or devices that present a chemical or biological hazard. Handling of terrorist type bombs encountered in public locations requires a disposal unit that is fairly small and mobile. The disposal of chemical and/or biological hazards requires that the disposal unit remain sealed throughout the explosion event, cleaning, and purging.

NABCO, Inc. is currently building a 42-inch blast chamber. This blast chamber is designed to contain and transport conventional explosive devices, such as terrorist bombs up to 10-lb of TNT equivalent explosives. This chamber is not designed to contain all the gas and by-products from an internal explosion.

This paper describes the new design to retrofit the existing 42-inch chamber with a new exterior door, a sealed penetration for the detonation wires, sealed penetrations for flooding and purging the system after the event, and hinge systems to rapidly open and close the chamber. This design will modify the chamber to remain sealed following an explosion event. The modifications are easy to retrofit and they will not interfere with the current application of the chamber. The closing system is simple and minimizes the amount of time an operator must spend in front of an open chamber. Finally, the modifications that seal the chamber from leaking gas products have redundancy to insure a safe detonation of a biological/chemical explosive device.

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1. Introduction

Recent national and international terrorist events have created a need for disposing of munitions or devices that present a chemical or biological hazard. Handling of terrorist type bombs encountered in public locations requires a disposal unit that is fairly small and mobile. The disposal of chemical and/or biological hazards requires the disposal unit to remain sealed throughout the explosion event, cleaning, and purging.

NABCO, Inc. currently builds two portable blast chambers. These spherical blast chambers are designed for the containment and transportation of explosive devices, such as terrorist bombs. The two chambers are 42 inches and 64 inches in diameter and are designed to be re-usable for a design basis explosives event, and to withstand a one time load from the maximum credible charge weight equal to approximately twice the design charge weight.

The current chambers are not designed to contain all the gas and by-products from an internal explosion. The subject of this paper is the retrofit of the existing 42-inch diameter Total Containment Vessel (TCV) to remain sealed following a detonation of an explosive device that has a biological/chemical hazard. The design includes an additional door on the outside of the chamber, a sealed penetration for detonation wires, sealed penetrations for flooding and purging the system after the event, and a hinge system to rapidly open and close the system. While the existing, interior blast door resists the initial and subsequent dynamic shocks from the explosion, a new exterior door seals the opening against loads from the quasi-static gas pressure,. The various ports on the chamber provide access for detonation wires and purging system equipment, while sustaining the physical abuse of the chamber vibrations. The ports also resist the shock pressures of the explosion source and the quasi-static gas pressure. This paper summarizes the more complex challenges encountered and the solutions that were engineered to produce a sealed blast chamber.

2. Design Criteria

The current TCV is used primarily as an explosive transportation unit to allow removal of the suspect device from public areas so that it can be disposed of properly. The 42-inch chamber is designed to totally contain the blast pressures (not gas pressure) from a 10-lb TNT equivalent charge, multiple times. However, the normal procedure is to transport the explosive device to a safe, remote location, remove it from the TCV, and detonate the device outside the chamber. The amount of time the operator spends in front of the door while it contains a suspect device should be minimized to protect them as much as possible. Therefore, the chamber must be easy to load and unload with minimal operator time in front of the chamber. Figure 1 illustrates the TCV chamber and transport trailer.

The new design included modifying the existing chamber to remain gas tight during the transportation and disposal of explosive devices that have potential biological or chemical hazards associated with them. The chamber must still perform its original blast containment function efficiently after modifications.

Figure 1. TCV Chamber

2.1 Objectives

The primary objectives of this design were to:

- Maintain the TCV as a conventional explosive device transportation and disposal unit.
- Maintain the ease of mobility of the TCV.
- Modify the chamber door opening to contain the blast as well as the hazards of an explosive device that has a biological and/or chemical threats associated with it.
- Modify the chamber to allow complete decontamination after the detonation of the device, including drain and purge ports and a detonation wire pass-through.

2.2 Design Considerations

The design team and the owner identified areas requiring special consideration for protection of operators and continued reliable operation of the chamber following a detonation. The first requirement was to keep the design simple and easily retrofit the modifications to the existing chambers. The current chamber design uses straight foreword methods for operation. It was desired to maintain this approach and avoid complicated designs that might create reliability and maintenance problems. A second requirement was to minimize the amount of time that an operator must spend in front of the door. Complex door closing systems might increase the time required for an operator to close the door, and increase the possibility of improperly closing the door.

Another design consideration was redundancy in the containment system for the biological/chemical hazards. Every opening and penetration has multiple barriers to contain hazardous substances.

The final consideration regarded maintenance. The new design requires the TCV to be used for disposal of explosive devices, not just transportation. Along with the increased

explosive activity in the chamber is an increase in appurtenances that require replacement or repair, such as o-rings and door seals. A proper maintenance schedule is required along with an inspection program for the TCV following each incident.

3. Loads

The new exterior door was designed for the quasi-static gas pressure resulting from a detonation in the chamber. The following scenarios were considered. The composition of C4 is 90% RDX with binder and additives[1]. RDX is $C_3H_6N_6O_6$. The basic reaction equation is: 1 $C_3H_6N_6O_6$ ---> 3 N_2 + 3 H_2O + 3 CO. Thus, 1 mole of explosive produces 9 moles of gaseous products. Ten lbs of C4 contains about 20.5 moles of explosives. A 21-inch radius sphere at ambient pressure and temperature contains approximately 26.5 moles of air. Thus, the gaseous products from the explosives contain approximately 7 times the number of moles that were originally in the chamber. After detonation, there is approximately 8 times the number of moles in the chamber compared to before the detonation. This is neglecting the extra volume for gas storage that was gained by detonating the solid explosive (about 0.5% increase).

Although the addition of moles raises the pressure, this is only important long after the detonation (minutes). The increased order of magnitude gas pressure is from the addition of heat during the early phases of the explosion (less than a few seconds), which raises the gas pressure.

If the detonation takes place in a nitrogen-purged environment, follow-on reactions are ignored. However, if there is any oxygen in the environment (dry air is about 20.95% oxygen), the after burning reaction which continues is: 2 CO + O_2 ---> 2 CO_2. Thus, combining 3 moles to get 2 reduces the total number of moles. This reduces the final pressure; however, the extra heat released raises the initial temperature and the initial pressure.

Since the sphere originally contained 20.5 moles of explosive producing 61.5 moles of CO (3*20.5), and there was only 5.5 moles of O_2 to start with (20.95%*26.5), the system will be oxygen deficient resulting in large amounts of CO.

Continuing to add oxygen, such as purging the system with pure oxygen to get 26.5 moles of O_2, will reduce the oxygen deficiency, release more heat due to the CO ---> CO_2 reaction, and end up with fewer overall moles. This has the effect of raising the initial temperature, raising the initial presure, and lowering the final pressure. The BLASTX[2] computer program takes the above chemistry into account and was used for final colculations. The predicted peak gas pressure from 10 lb of C4 in an oxygen-purged environement was 1,900 psi. The final pressure for the three cases discussed above (nitrogen purged, ambient air, and oxygen purged) was on the order of 110 – 120 psi at approximatley ambient temperature after one minute.

The second consideration for controlling gas loads assumed the chamber had a large pressurized tank containing a hydrocarbon for a fuel-air bomb. In this case, the initial

pressure in the entire chamber could be raised following loss of the tanks' structural integrity (P1 * V1 = P2 * V2). The worst case scenario assumed complete loss of the structural integrity of the tank, resulting in an atmosphere inside the chamber undoubtedly fuel rich. However, as the fuel rich atmosphere mixed by diffusion with the air in between the interior blast door and the new exterior door, a stoichiometric mixture could occur at some point. Ignition of this stoichiometric mixture, at maximum initial pressure, would then produce the worst case loads. By assuming a fairly available tank of hydrogen, and a dynamic load factor of 1.8 applied to the detonation pressure, the controlling design load of 2,000 psi was determined using the MASA Chemical Equilibrium Code[3]. Reflection factors were not considered in this load case, as it was assumed that the travel of the flame front would not be perpendicular to the door over a significant portion of its surface area.

A variation of the above was to assume an equally available acetylene bottle. Acetylene is known to decompose in the absence of oxygen. Acetylene also becomes increasinlgy unstable as pressures exceed 15 psi. Thus, loss of structural integrity of an acetylene bottle would raise the chamber's internal pressure, and ultimatly lead to a voilent reaction of the acetylene. For this study, it was assumed that the decomposition took place at a presure of less than 50 psi. This produced similar loads to the hydrogen case dicussed above.

Therefore, based on the loading conditions discussed above, a static pressure of 2000 psi was used for the design of the new exterior door. The exterior door was not designed for the dynamic blast loads because they are suppressed by the internal blast door.

In addition to the quasi-static gas pressure, the penetrations through the main body of the chamber were designed to resist the initial dynamic loads that follow a detonation. The penetrations also had to be designed to resist the large accelerations of the chamber wall as it expanded and contracted in response to the contained explosive charge. These accelerations were calculated using the dynamic numerical modeling code, Autodyn[4].

4. Structural Modifications

The current TCV is a 42 inch sphere made of HY 80 steel, with a 21 inch round port on one side supported by a reinforcing ring. The chamber's internal door seats against the support ring at the chamber opening. The door is lifted into place by a winch mounted outside the chamber at the top of the ring and held in place by a five-armed brace called the "spider". Figure 2 illustrates the chamber with the door and spider.

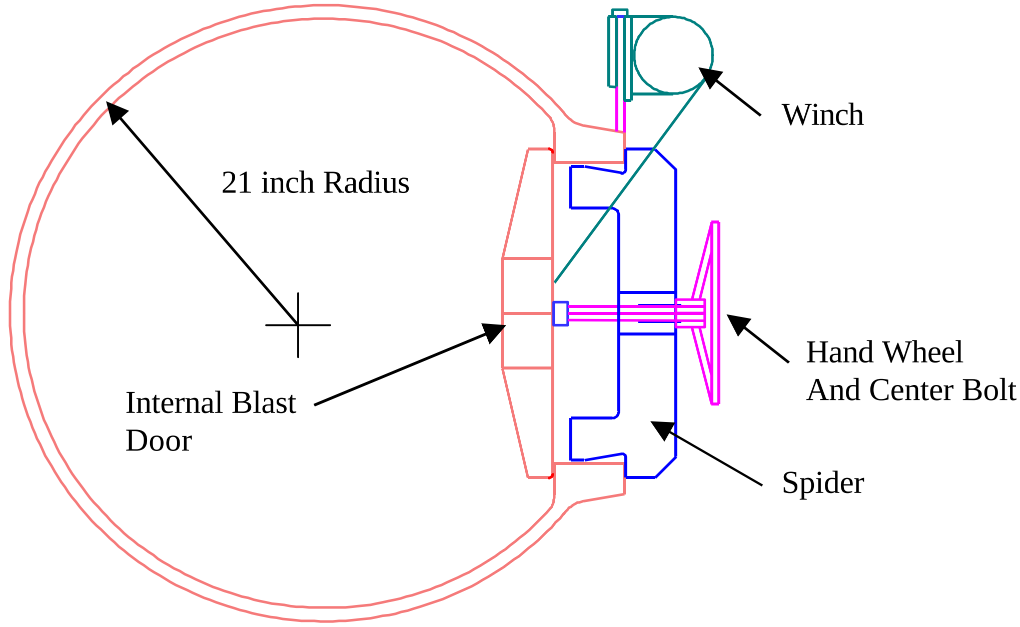

Figure 2. Current Chamber Cross Section

4.1 Interior Door

The interior door is designed to resist shock and quasi-static blast loads and fragments. The only modifications to the interior door were on the closing system, which consists of the spider and a center bolt with a hand wheel. In the original design, the spider bears against the outside of the support ring and the center bolt holds the spider and door in place (see Figure 2). The hand wheel is used to simplify tightening the center bolt. Once the center bolt is in place, the winch can be removed.

In the modified design, the spider was relocated inside the support ring to make room for the new exterior door that is designed to resist the quasi-static gas pressure produce after a contained detonation. Figure 3 shows a section of the modified chamber with the new location of the spider. Care was taken not to modify the center bolt and hand wheel. It was desired to keep the stiffness of the center bolt the same due to the complexity of its design. The original design of the center bolt was based on both analytical calculations and empirical test data to determine the correct balance between the stiffness of the spider, the stiffness of the center bolt, and the mass of the door. The hand wheel design remained unchanged to maintain simplicity of closing.

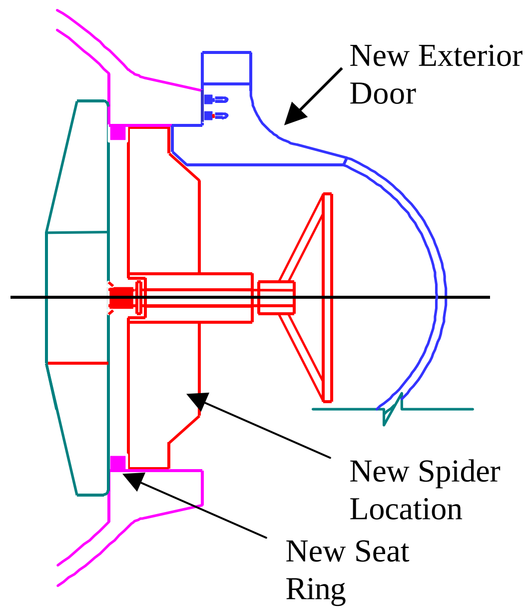

Figure 3. New Spider Location

4.2 New Exterior Door

A new exterior door was designed to seal the door opening against any venting or release of biological/chemical hazards during or following a detonation. The external door is protected from the high-pressure shock loads by the internal door and is designed to resist the quasi-static gas pressure leaking past the door.

The new exterior door is semi-hemispherical, made of HY 80 steel (See Figure 4). The semi-hemisphere door shape has two major advantages over a flat door design. First, the semi-hemisphere produces a more efficient design. Second, the semi-hemisphere door can be closed without interfering with the operation of the interior door closing system.

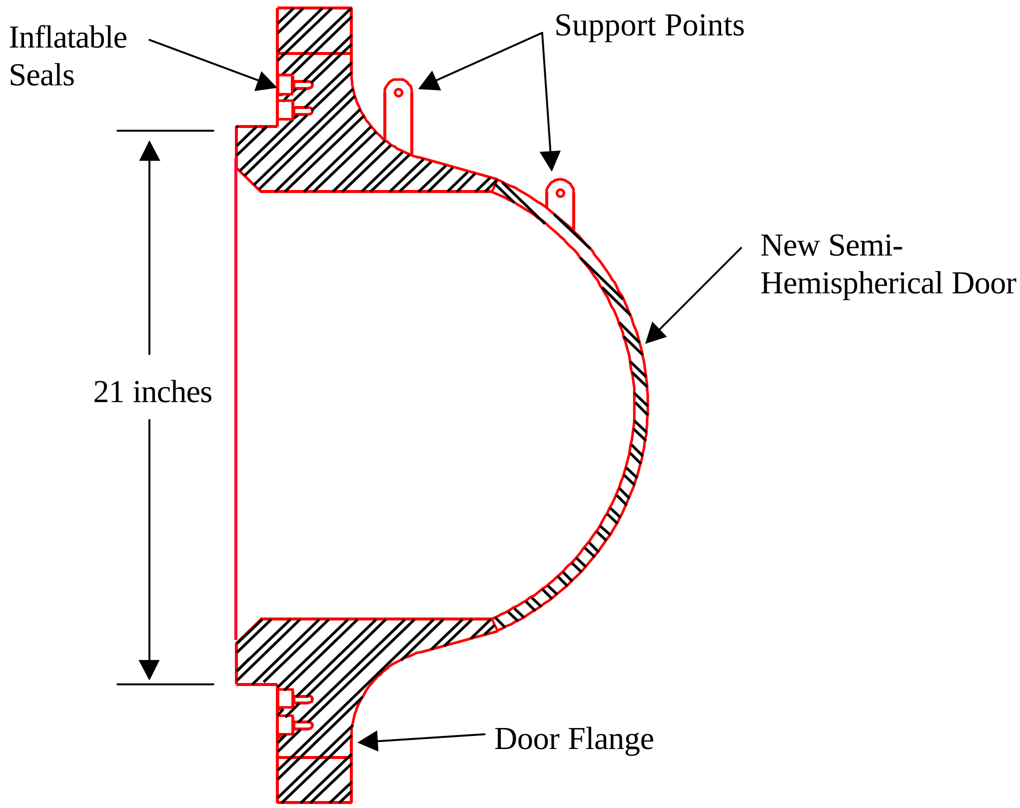

Figure 4. New Exterior Door Cross Section

The new exterior door was analyzed using a finite element (FEM) computer code. Figure 5 shows the FEM model of the exterior door with stress contours. The highest stress regions were located at the intersection of the flange of the door and the semi-hemisphere.

Two inflatable seals seal the new exterior door to the face of the support ring. The two seals are consistent with the multiple barrier design philosophy. These seals are inflated with a pressurization system that can be operated remotely. A pressure detection system monitors the pressure in and between the seals to track performance during and after a explosion event.

The new exterior door is secured in place with swing bolts mounted on the outside of the support ring. Swing bolts were selected to eliminate the operator having to deal with loose hardware when closing the exterior door. The TCV chamber and exterior door with swing bolts are shown in Figure 6.

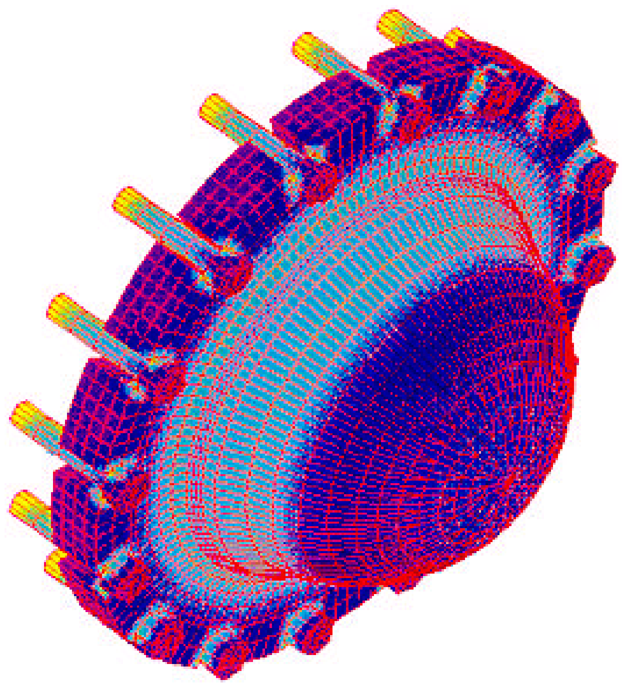

Figure 5. FEM Model of Exterior Door

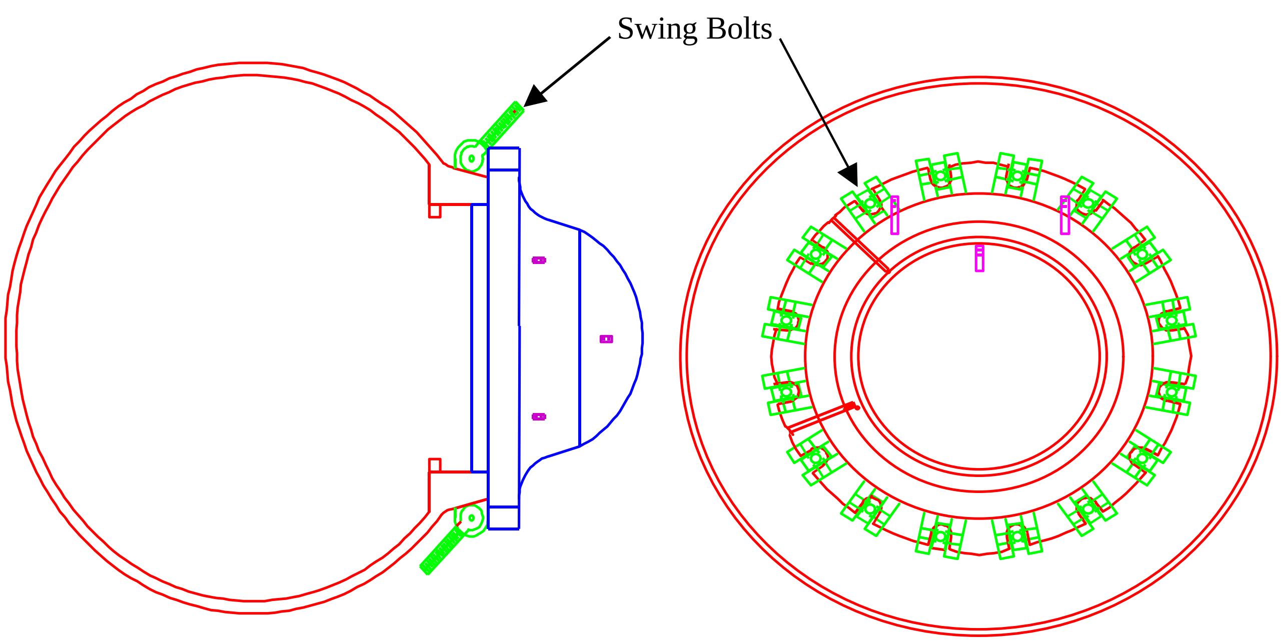

Figure 6. TCV Chamber and Exterior Door with Swing Bolts

5. Secondary Components

Several penetrations were designed for the modified TCV, including purge and drain ports and a detonation wire pass-through. Penetrations in the main compartment of the chamber were designed to resist the shock loads, fragments, and large accelerations of the chamber wall. Drain and purge ports located in the space between the two doors are not exposed to the dynamic blast loads or fragments. All of the penetrations have multiple barriers to contain the explosive products.

5.1 Locations

A purge port was located at the top of the chamber and at the top of the compartment between the doors so both areas could be decontaminated following the detonation of a biological/chemical explosive hazard. A drain port was located in the bottom of the chamber and at the bottom of the compartment between the doors so both areas could be drained. A third drain port was located just below the lower edge of the support ring as a safeguard. In the event that the drain at the bottom of the chamber does not function due to debris from the explosion, the third drain will drain the chamber to the point that the door could be lowered without spilling the decontamination products. After the door is lowered the remainder of the tank could be pumped out. The drain in the compartment between the doors is not expected to clog from debris. No penetrations are located opposite of the door due to the high load concentrations in that area. See Figure 7 for a front view of the chamber that shows the penetration locations.

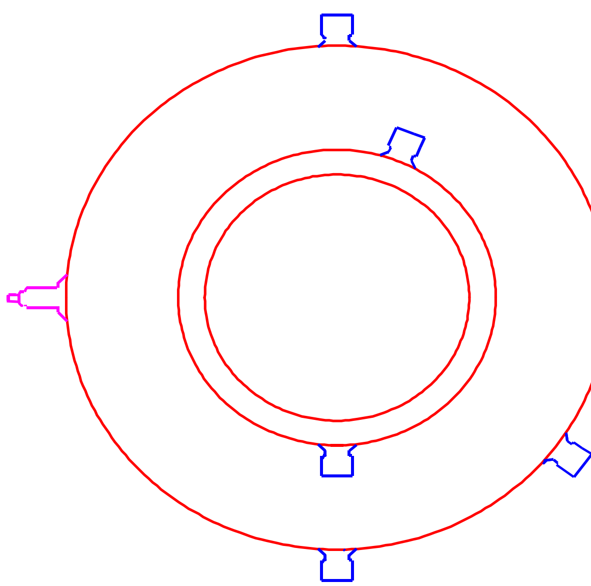

Figure 7. Penetration Locations

6. Ancillary Parts

To meet design requirements, new modifications were designed to minimize the operator effort and maintain the performance of the TCV chamber as a conventional explosive device transportation and disposal unit. The new exterior door and the spider are supported during opening and closing by hinge systems. A top view of the two hinge systems is shown in Figure 8. Because of the large accelerations of the chamber during a detonation, the two hinge systems must be removed from the chamber after the spider and door are in place. Both hinge systems can be easily detached from the chamber by simply removing quick-release pins. This reduces the operator time spent in front of the chamber with a device inside.

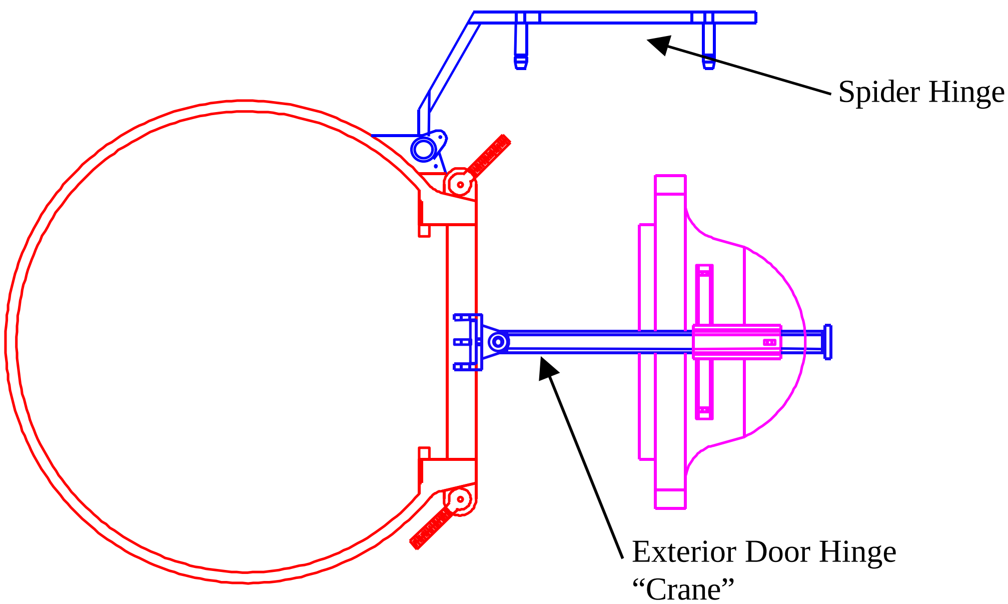

Figure 8. Exterior Door and Spider Hinge Systems

6.1 Exterior Door Hinge

The hinge system, or “crane”, is mounted on the top of the support ring to mobilize the door. Figure 9 shows a side view of the exterior door suspended from the crane hinge system. The door is suspended from the crane by two turnbuckles, which are attached to the door by two quick-release pins. The crane can quickly be removed from the chamber by pulling two pins on the door and one on the crane. The turnbuckles can be adjusted to allow the door to line up with the chamber before each use. The crane will move the door in and out of position as well as rotate it to the side of the during the loading process. It can also be stored at the side of the chamber when it is not required. Moving parts of the crane have sealed bearings to ensure ease of operation.

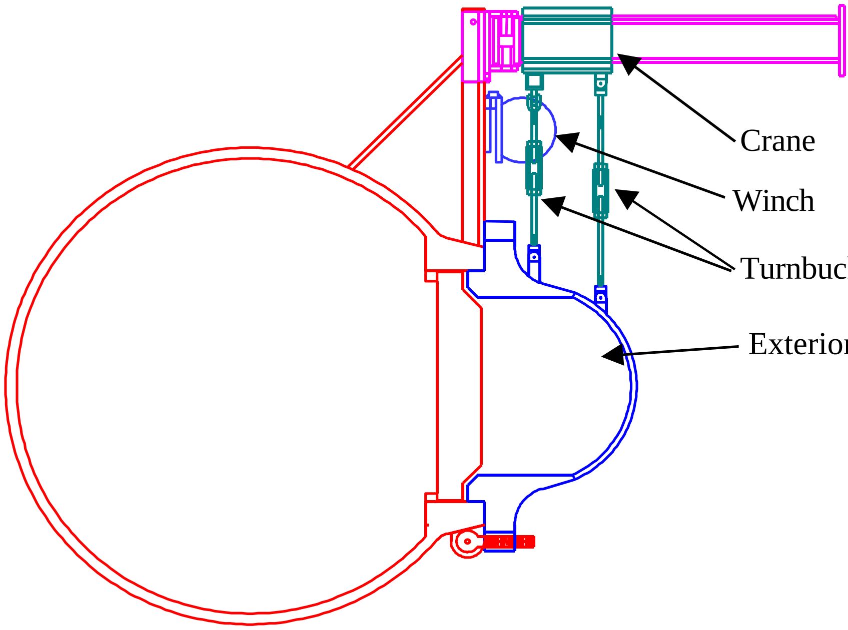

Figure 9. Exterior Door Crane

6.2 Spider Hinge

Figure 8 shows a top view of the chamber with the spider hinge attached. Two views of the spider hinge are shown in Figure 10. The spider hinge is a plate that pivots around the side of the support ring. The plate has a large hole in the center to access the hand wheel on the center bolt of the spider. Two pins on the hinge plate support the spider. Once the hinge plate is in front of the chamber, the spider can be moved into place and the center bolt tightened. The hinge is removed from the chamber by pulling the pin on which the hinge rotates. To remove the spider the process is reversed.

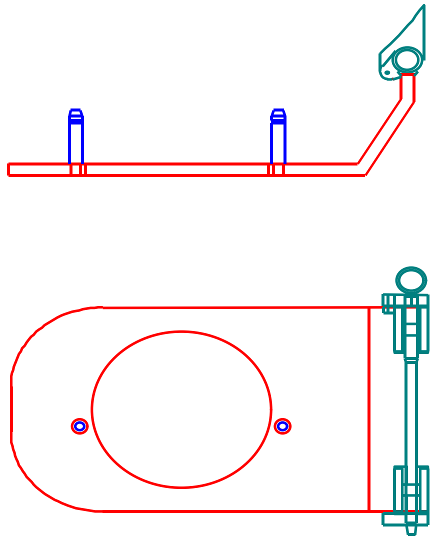

Figure 10. Spider Hinge

7. Conclusions

NABCO, Inc. is currently building a 42-inch blast chamber. This blast chamber is designed to contain and transport conventional explosive devices, such as terrorist bombs up to 10-lb of TNT equivalent explosives. This chamber is not designed to contain all the gas and by-products from an internal explosion.

A retrofit of the existing TCV chamber with a new exterior door, a sealed penetration for the detonation wires, sealed penetrations for flooding and purging the system after the event, and hinge systems to rapidly open and close the chamber. This design was initiated to modify the chamber for full containment. The modifications are easy to retrofit and they will not interfere with the current application of the chamber. The closing system is simple and minimizes the amount of time an operator must spend in front of an open chamber. Finally, the modifications that seal the chamber from leaking gas products have redundancy to insure a safe detonation of a biological/chemical explosive device.

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[2] Britt, J.R., "Internal Blast and Thermal Environment from Internal and External Explosions: A User's Guide for the BLASTX Code, Version 3.0," Contracts DACA39-93-C-0015, DACA39-93-C-0023, DACA39-93-C-0096, SAIC Report 405-94-2, May 16, 1994.
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